0.097	0.020	0.888	0.012	3.806	150.54	0.876	5.2610
0.123	0.022	0.823	0.020	3.806	150.54	0.802	6.2340

THE APRIL 1960

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Published by the Georgia Tech Engineering Experiment Station

ANTOINE VAPOR PRESSURE CONSTANTS
FOR ANILINE A= 7.24179 B= 1675.3 C= 2
FOR N-HEPTANE A= 6.9024 B= 1268.115 C= 2

I	II	III	IV	V	VI	VII	VIII
0.003	0.001	1.133	0.001	3.806	150.54	1.131	2.9180
0.003	0.001	1.135	0.000	3.806	150.54	1.135	2.8950
0.003	0.001	1.129	0.000	3.806	150.54	1.129	2.9360
0.005	0.001	1.126	0.000	3.806	150.54	1.125	2.9610
0.006	0.002	1.120	0.000	3.806	150.54	1.119	3.0020
0.008	0.002	1.121		3.806	150.54	1.121	2.9920
0.010	0.003	1.105	0.000	3.806	150.54	1.105	3.1050
0.016	0.005	1.094	0.000	3.806	150.54	1.093	3.1870
0.017	0.005	1.089	0.000	3.806	150.54	1.088	3.2230
0.020	0.006	1.088	0.000	3.806	150.54	1.087	3.2310
0.023	0.007	1.077	0.000	3.806	150.54	1.077	3.3100
0.022	0.007	1.101	0.000	3.806	150.54	1.100	3.1340
0.023	0.007	1.094	0.000	3.806	150.54	1.094	3.1810
0.025	0.007	1.071	0.001	3.806	150.54	1.070	3.3650
0.030	0.008	1.058	0.000	3.806	150.54	1.057	3.4660
0.046	0.012	1.021	0.006	3.806	150.54	1.015	3.8140
0.062	0.015	0.978	0.005	3.806	150.54	0.973	4.2060
0.077	0.017	0.932	0.008	3.806	150.54	0.924	4.7040
0.097	0.020	0.888	0.012	3.806	150.54	0.876	5.2610
0.123	0.022	0.823	0.020	3.806	150.54	0.802	6.2340

END OF DATA

MARGULES CONSTANTS A12 = 1.1400 A21 = 0.2337
MARGULES CONSTANTS A12 = 1.1430 A21 = 0.8704

X	CALC RATIO	OBS	R(I)	R(I)	LOG F1	LOG F2	Z
0.003	1.132	1.131	0.0007		1.132		0.003
0.003	1.132	1.135	-0.0029		1.132		0.003
0.003	1.131	1.129	0.0025				0.003
0.005	1.125	1.125	-0.0003		1.125		0.005
0.006	1.124	1.119	0.0047		1.124		0.006
0.008	1.118	1.121	-0.0028		1.118		0.008
0.010	1.112	1.105	0.0073	0.0001	1.112	0.000	0.010
				0.0001	1.098	0.000	0.016
				0.0001	1.094	0.000	0.017
				0.0001	1.088	0.000	0.020
0.023	1.080	1.077	0.0029	0.0001	1.080	0.000	0.023
0.022	1.081	1.100	-0.0191	0.0005	1.082	0.000	0.022
0.023	1.079	1.094	-0.0146	0.0007	1.080	0.000	0.023

The Spectrum of Computation

VOLUME 15, NO. 2 APRIL, 1960

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the cover

The cover photograph shows a typical page of output from one of the machines at the Rich Electronic Computer Center. The data shown concerns a problem in chemistry, but it might just have well concerned a study in nuclear physics, the computation of a payroll, the determination of a satellite orbit, the analysis of an opinion poll, or even research in theology. For Georgia Tech's computational facilities are serving a broad spectrum of data processing and research needs at the Institute and in this area. More about the machines, the men and the methods of high-speed computation is presented on pages 5 through 11.

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The President's Page

EVER SINCE ARISTOTLE and his students first began their organized studies of plants and animals, the science of biology has accumulated a vast library of information about living organisms. This information has served as the foundation for advances in medicine, agriculture, and many related fields such as public health, pharmaceuticals, and insect control.

However, the practical problems associated with the care or control of living things involve more than biological facts. Knowledge of the functions of biological materials in their environment, and the techniques of other engineering and physical sciences are usually employed. The result is a distinctly different discipline in biological work generally called applied biology.

Georgia Tech has had a long-standing interest in applied biology. At one time, the Institute offered a degree in Public Health Engineering. And students, especially civil engineering majors with an interest in sanitation, have taken courses in biology for more than thirty years. Research efforts have resulted in significant publications in such areas as frozen foods, airborne bacteria, radiation effects, sewage treatment and industrial waste control. In fact, researchers in applied biology are among our most prolific contributors to scientific and engineering journals.

But biological problems are increasing in frequency and complexity. The expansion of industry in the South and elsewhere is a contributing factor, not only because of the growing need for improved waste control, but also because of the new manufacturing techniques employed. New chemical processes and the industrial uses of radioisotopes present new biological questions that must be

continued overleaf

answered. Most of the potential benefits of radiation, such as the preservation of foods, are far from practical realization. The brand new problem of the manned space ship, with its closed biological system, is another example of the major challenges in applied biology.

Now Georgia Tech's Department of Applied Biology has been authorized by the Board of Regents to become a degree-granting school. The approved curriculum is a rigorous one, with strong requirements in chemistry and physics. The objective is to produce individuals who can understand how biological organisms function and learn how to control them in the real chemical and physical systems in which they occur. For example, the applied biology major may minor in chemistry, and thus become qualified for work as a biochemist in medical and pharmaceutical research. Studies in chemical engineering will prepare one for work with industrial fermentation processes. A minor program in physics and radiochemistry may lead to positions in health physics or radiation biology—both growing fields in this nuclear age. In any case, the curriculum will stress fundamentals and prepare the student for post-graduate study.

The research program which complements the instructional program has been improved by the new Radioisotopes and Bioengineering Laboratory, while the coming research reactor may incorporate arrangements for medical and other biological research.

The development of strong programs in applied biology at Georgia Tech is not the result of student demand or a special interest of industry in the South. It is not our mission to meet demands. Rather it is our business to anticipate these problems and then to encourage and prepare students and to develop techniques to solve them when they arise.

E. D. Harrison

President

Computer Calisthenics

The first of three articles on high-speed computation at Georgia Tech emphasizes the maintenance and modification work on the machines.

by S. P. Lenoir, Special Research Engineer

THE CARE AND FEEDING of digital computers is no small task. The staff responsible for maintaining the two large-scale machines of the Rich Electronic Computer Center consists of four engineers and three technicians full-time, and one engineer and two technicians part-time. This staff keeps the Burroughs 220, the Univac Scientific (ERA 1101), and some auxiliary equipment in operating condition.

The operation of this equipment and the preparation of data for the computers (not including programming services) is accomplished by four full-time and two part-time employees.

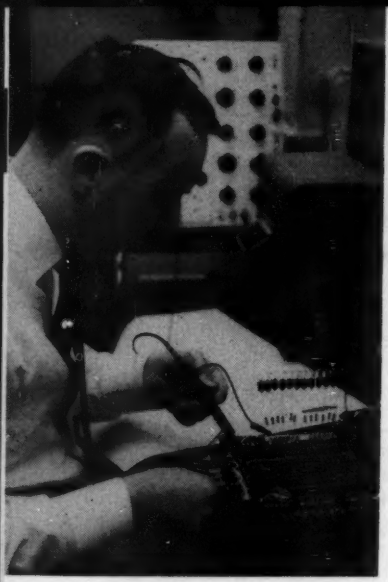
In machinery consisting of many thousands of parts, there are obviously many thousands of things that can go wrong. The ERA 1101, for example, contains over 3,000 vacuum tubes and about an equal number of germanium diodes. These are the elements most subject to failure. In the class of elements with a relatively low failure rate are thousands of resistors and capacitors, hundreds of relays, switches, and pulse transformers.

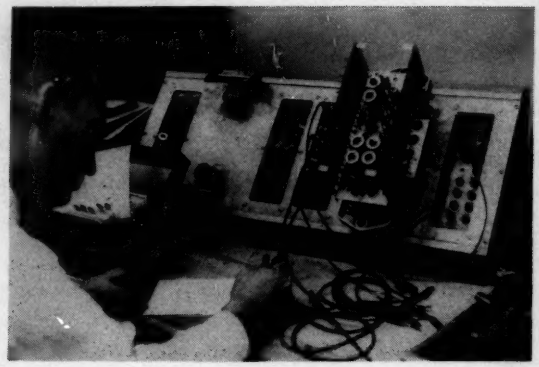
The elements in a general purpose computer such as the ERA 1101 are physically interconnected in such a manner that they can electronically form many channels through which information can flow. Also, these channels may be electronically interconnected to form a complex of series-parallel information paths. Each basic step in performing a computation, called an instruction, causes at least one particular interconnection of channels and sometimes several such interconnections in time sequence. Furthermore, the number of elements comprising a given channel, the interconnection of channels, and sometimes entire instructions to be executed in the future can be affected by the information in the channels, either past or present. The number of possible arrangements is staggering.

Electronic Sleuthing

The best maintenance procedure is then to test as many of these arrangements as possible, as often as possible, in the order of their frequency of occurrence. The fastest method of testing a computer, since it is inherently a high speed device, is to allow it to test itself by executing a program for which it has been supplied the correct answers. Such a testing program, called a diagnostic routine, should test a large number of the most frequently encountered interconnections by causing known information to flow through the channels and then compare the result with the correct result. If the comparison indicates correct operation for all interconnections tested, the entire routine is repeated endlessly until manually stopped. If any comparison indicates an error, the routine causes indicative information to be displayed visually in console registers and causes the computer to stop.

The information displayed usually gives the maintenance engineer only a clue as to which general area, or areas,





Photographs by Cecil Phillips

Left. The author works on part of the card input-output system for the 1101. *Center.* Engineer Leon Kinard records results of 1101 tube chassis test. *Right.* A package in the tape storage unit of the 220 is replaced by Leigh Steves.

might contain the faulty element. He must now exercise his own judgment as to what to do next. At this stage of trouble-shooting the "shot-in-the-dark" method is notoriously unsuccessful and time-consuming. Replacing any element or group of elements at this time may even introduce a different type of error which will only compound his troubles. In the most unfortunate of circumstances he may introduce a compensating error!

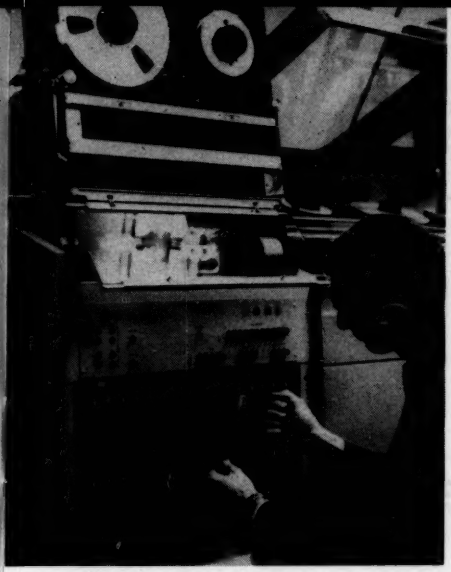
Since a good diagnostic routine executes only a very few program steps before checking for correct operation, the engineer should now manually cause the computer to repeat those steps which caused the error. He also slows down the computer to permit the execution of only one step at a time. By carefully scrutinizing the console registers before and after each step, he should be able to locate the program step that causes the error.

If necessary, the computer can be slowed down even further so as to display all the intermediate results of a given program step. This slow-down is accomplished by substituting a manual pushbutton which emits only one pulse per depression instead of an oscillator which emits 400,000 pulses per second.

The engineer should now be able to either conclusively pinpoint the faulty element or the area which contains this element. In the latter case, he will either select another diagnostic routine which tests the suspected area more exhaustively or compose his own test extemporaneously.

Faulty elements that cause intermittent errors are the most difficult to locate. Therefore a special effort is made to force these borderline elements to fail by executing the diagnostic routines under adverse conditions, e.g., with reduced vacuum tube heater voltage, or with one or more of the supply voltages set either higher or lower than its nominal value. When a trouble has been localized by the above procedures to one chassis containing between 10 and 16 vacuum tubes and their associated circuitry, it is replaced by a spare chassis and the routines are repeated until error-free operation is obtained.

In addition to any chassis removed because of known troubles, a few chassis are removed each day on a rotating basis. All tubes in these chassis are then tested and replaced if faulty or marginal. During each maintenance period, which lasts from one to two hours each morn-



ing, all those chassis which were repaired the previous day are tested in the computer under actual operating conditions.

The maintenance staff is constantly in search of methods to improve existing diagnostic routines. Achieving the ultimate of routines would virtually eliminate the need for a maintenance engineer, since the computer would be capable of locating its own faulty components with 100 per cent accuracy! However glamorous this may sound it is impossible to achieve, for in a computer without redundant circuitry there always exists at least one component without which the computer cannot even execute its diagnostic routine properly.

Design and Modifications

In addition to maintaining the computers the engineering staff devotes part of its time to the design and development of desirable auxiliary devices, for example paper tape handling equipment. When an X-Y Plotter was purchased, additional circuitry was designed to allow punched paper tape to be used as an input medium. The plotter is now capable of plotting points on rectangular co-ordinate paper corresponding to data entered from paper tape, punched cards, or from a manually operated keyboard.

Occasionally it is found desirable to modify the computers, sometimes extensively. For example, 4096 words of magnetic core storage were recently added to the 1101. This not only increased its storage capacity by 25 per cent and considerably decreased the time required to execute a program, but greatly simplified the task of writing a program.

A punched card input-output system is currently being developed for the 1101, which, it is hoped, will expand the class of problems currently being solved. For instance, if the input data already exist on punched cards it is more economical to use a computer that can read these cards directly than it is to convert the cards to some other medium that a different computer can read, the computers being otherwise equivalent. The same reasoning applies if the output data are required on cards.

The new card system will consist of two small magnetic core storage buffers which act as an intermediate depository for information passing into and out of the computer. The circuitry associated with these buffers will serve to synchronize the timing between the high-speed computer and the low-speed card reader and punch. Transistors will be used almost exclusively in this system.

The Burroughs 220 computer is capable of using three different input-output media: punched paper tape, punched cards, and magnetic tape. Of the three, magnetic tape is much the fastest; however at present we have no off-line magnetic tape equipment. A system for converting punched cards to magnetic tape and vice-versa is being investigated.

At some time in the future it is hoped that an entire digital computer will be designed and built here at Georgia Tech. As a first step in this direction, a staff member was granted a year's leave-of-absence last year to participate in a similar program at the University of Illinois. Experience in the latest computer techniques, thus gained has broadened the view point of our entire staff.

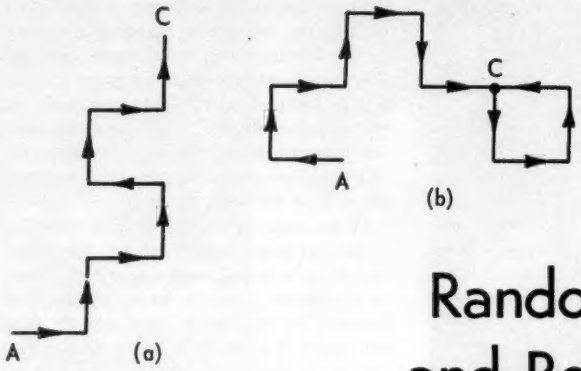


Figure 1

Random Walks and Registration

by Irwin E. Perlin, Research Professor of Mathematics

A TRADITIONAL PET NAME for mathematics is "the Queen of the Sciences." Electronic computers are often referred to as "slaves." In a sense this hierarchy is apt. For the mathematician is certainly the intellectual superior to the machine, which only follows orders.

However, computers follow orders exceedingly well. So well that they often embarrass their masters by unfailingly pointing out erroneous or inconsistent orders. Furthermore, computers remember orders admirably and execute them with unbelievable speed. The result is that the user of the machine may successfully complete projects that would be practically impossible otherwise. Thus the computer is no ordinary slave. Rather, it is a talented assistant, one that greatly enhances a capability for data processing, engineering computations of many types, and scientific research.

Here in the Mathematical Analysis Group of the Rich Electronic Computer Center, digital machines are used to help solve problems in mathematical research. Satellite orbit calculations, homing devices, radio frequency assignments, and numerical analysis studies are some of the research problems which have been investigated. Among the current studies are the restricted random walk and the scheduling problems.

Briefly, a restricted random walk can be defined as a network of lattice points generated by the step-wise linear evolution of unit length vectors from some origin in such a manner that there is no double occupancy of any lattice site.

Since no two chain units of a flexible long-chain polymer molecule can occupy the same volume element in space, a restricted random walk provides a convenient model for describing the mean dimensions of long-chain polymers, such as rubber molecules.

The present investigation concerns one type of restricted random walk, which can be described as a two-dimensional, two-choice, 90° restricted random walk. The object of the study is to obtain exact analytical methods for predicting the total number and average length of walks of any prescribed number of steps.

Figure 1(a) shows a path of eight steps. Starting at point A, one chooses

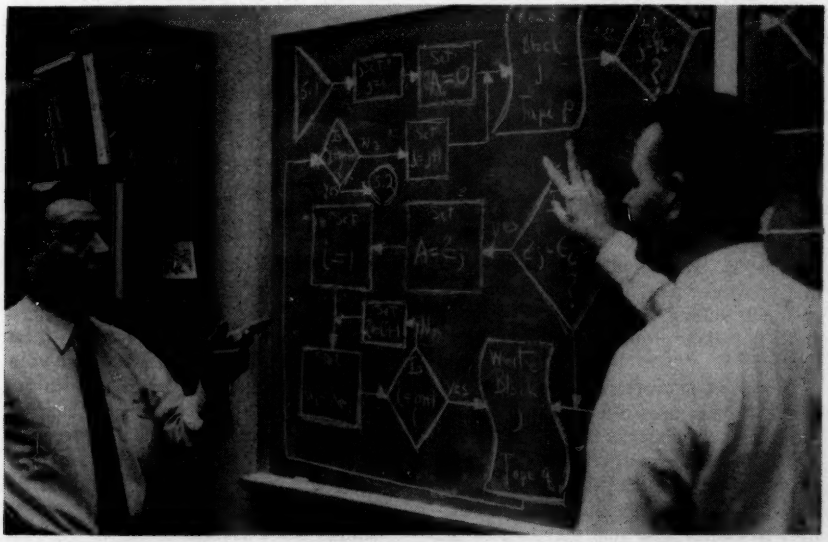
a horizontal step, either to the right or to the left. In this case a choice has been made to the right. Then a choice must be made in the vertical direction, etc., until the eight steps have been completed at point C.

In figure 1(b) a path has been generated which must be excluded because the point C has been occupied twice. One part of the study underway is to determine the number of existing paths (paths containing points which have been occupied more than once must be eliminated) after n steps. The UNIVAC SCIENTIFIC (ERA 1101) has been utilized to aid in this investigation. The computer generates all possible paths of the type previously described through twenty-three steps. Certain new results, which have led to the discovery of new techniques, have been obtained. It might be well to mention that while there is an extensive literature which treats the restricted random walk statistically, there is none utilizing exact analytical methods.

The scheduling problem is concerned with the assignment of students to classes. Specifically, the problem can be stated as follows: Each student selects the courses that he wishes to take. From this information, it is desired to produce a master schedule of classes, schedule of rooms, assignment of instructors, and student registration, so that a minimum number of conflicts occur. Because of the magnitude of the task, electronic computers shall be utilized to process the entire procedure.

Heretofore, computer applications of the registering of students have been confined to fitting students into an existing master schedule of courses. The present investigation is directed along the lines of producing a master schedule based on student selection of courses. Of necessity, some student choices may have to be overlooked. Methods are being sought which will produce master schedules involving a minimum number of conflicts. Some preliminary investigations have been made and tentative plans formulated. The techniques developed thus far seem promising.

Dr. Perlin (left) and the Computer Center's senior programmer, Charles Reed, discuss a flow diagram, which is usually the first step in preparing a program for a computer.



by John H. MacKay

Head, Statistical Analysis Group

Red Tape, Paper Tape

THE RED TAPE of the business world has effective opposition nowadays in the paper tape, magnetic tape and punched card systems of electronic computers. These machines are finding more and more application in the routine operations of commercial and professional enterprises. Among the jobs a computer may perform are payroll calculations, customer billing, solution of scheduling and allocation problems, and inventory control.

Business and professional organizations in the Atlanta area often encounter data processing or statistical problems of these kinds, which seem to require the use of electronic computers. Often a firm in such a situation will send its representatives to confer with staff members of the Rich Electronic Computer Center at Georgia Tech.

At the conference the Computer Center's mathematicians, statisticians and other experts obtain information about the problem background, the data available, the types of decisions necessary, and any additional information required. The outcome of such a meeting may well be the decision that the computing or data processing job is not big enough for economical computer calculation, or that for other reasons a computer application is not warranted.

Often it is decided that a certain computer or combination of computers can be used effectively on the problem. In such case a cost estimate is built up which gives consideration to the times required for analytical work, programming, computing, and interpretation of results. In complex situations a preliminary or feasibility study may be recommended. These preliminary discussions frequently lead to contractual arrangements.

Georgia Tech has three large digital computers, each with its own capability and advantages, as well as an extensive general purpose analog facility. A digital computer rapidly processes collections of numbers (input data), performing additions, multiplications and so on according to a set of instructions called a "routine." The writing of this routine is called "coding" and is part of the programming job. A routine is set up in such a way that the desired end result is calculated in the most efficient (least time consuming) manner.

A general purpose analog computer is a collection of electronic devices each of which performs a particular arithmetical operation. These devices are so arranged that they may be interconnected to form an electrical system in which certain voltages and currents vary with time in accordance with a predetermined system of differential equations. Analog programming is the process by which one discovers the optimum set of interconnections to achieve the proper time varying voltages and currents.

Digital computers are designed for the solution of scientific and engineering problems requiring a high degree of computational accuracy, and for data processing. The computations are usually repetitive, being based in each repetition on a different set of discrete input data selected from the memory.

In a typical digital computer application an analytical solution (formula) is available. Problem areas suitable for treatment by digital machines include linear programming for industry, factor analysis, scheduling and prediction problems, analysis of covariance models with nested variables, and Monte Carlo studies.

Analog computers are designed to process continuous input data and are often used when input and output functions are related in an unknown manner, that is, when no analytical solution is available. They are often used in connection with Monte Carlo methods. In a Monte Carlo study, input functions are generated which behave statistically like the ones expected in practice. Output functions resulting from different courses of action are noted, and that course of action is chosen which most frequently produces a desirable output.

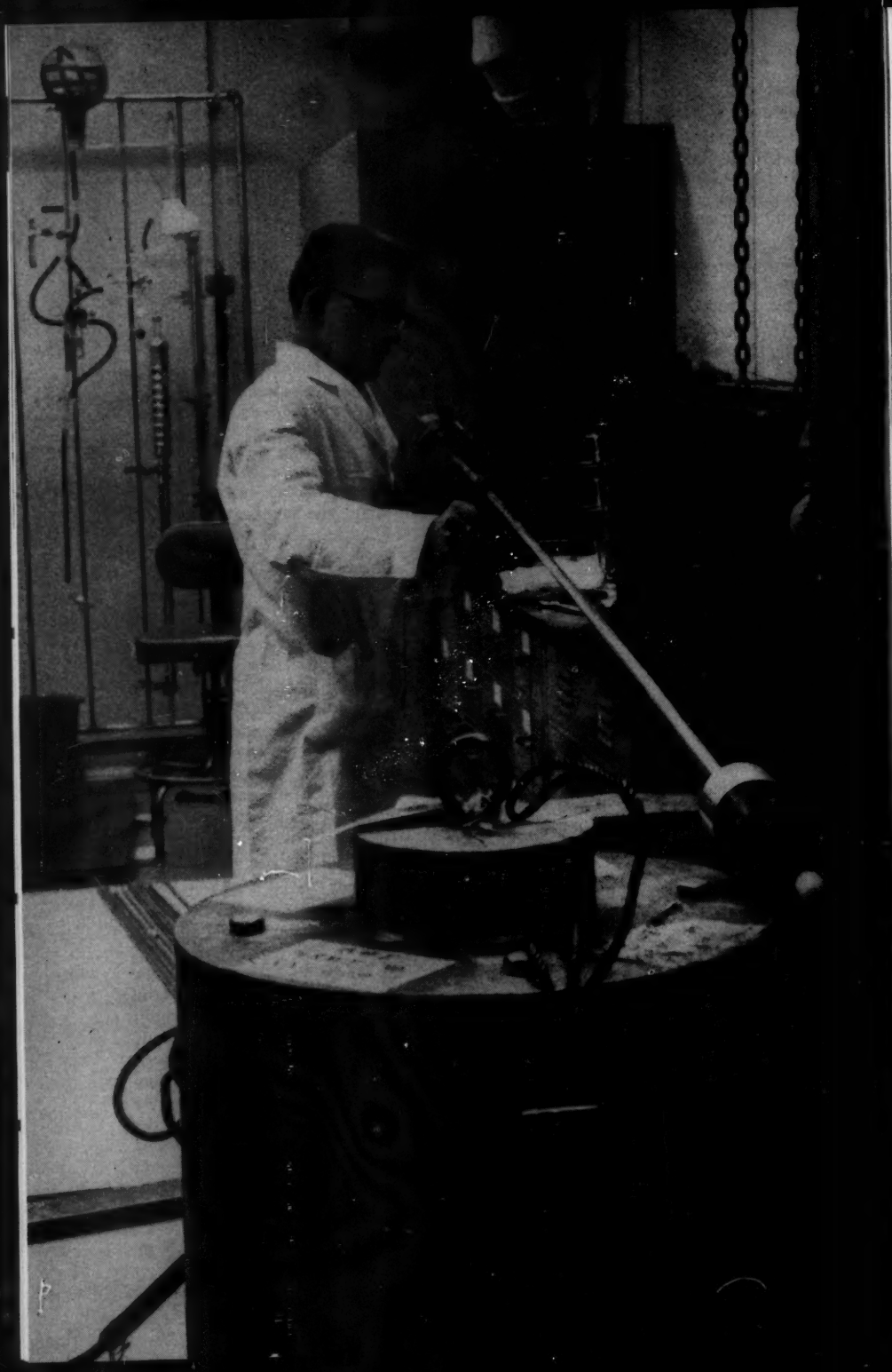
For example, the Monte Carlo method might be used in a study of the zeros of a continuous random time function. The number of times the graph of such a function crosses the time axis on an interval of fixed length is a discrete random variable whose probability distribution is related to that of the original function in a very complicated way. The expected value (statistical average) of this random variable can be determined analytically, but the complete probability law cannot.

The noise generator component of an analog computer can generate a sequence of such random time functions of the proper length, and other computer components can be so interconnected that a count of the number of zeros is recorded for each function in the sequence. The percentage of counts exceeding any constant is an approximation to the probability that the random variable exceeds that constant. The number of functions processed can be chosen large enough so that the approximation error is less than a prescribed amount with probability arbitrarily close to unity.

The author (left) talks random number generators with analog expert Bob Johnson at Georgia Tech's Analog Computer Laboratory.

In spite of their versatility and calculating efficiency, there are several rather important things that computers cannot do. A computer cannot think, and although it can do arithmetic very rapidly, it is unable to do even the most trivial mathematical analysis. Another shortcoming of computing devices is a limitation on the decimal accuracy of results. The results of analog calculations are particularly subject to computational error. Mathematical analysis must be made to determine the quantities to be calculated, minimize the effect of computational error, and provide a basis for the interpretation of results.

The real key to successful use of computers in dealing with practical problems is the effective employment of scientific and technical personnel, especially mathematicians and statisticians. Such experts are needed to decide how best to summarize the available data, how to use the summary information in making decisions or predictions, and to determine what kind and what quantity of additional information is required for a solution.



Left. Van Willis uses "Long Tom Cutie Pie" for radiation survey around the 3750-lb. carrier. *Above.* Top view of well shows its tube nest. *Right.* Carter shows Dr. Fred Sicilio tubes like those holding the Cs-137.

Photographs by Cecil Phillips

NEW RADIATION SOURCE

ON A FRIDAY EVENING in January, personnel of Georgia Tech's Radioisotopes and Bioengineering Laboratory installed a new and unique radiation source. The source amounted to 12,000 curies of cesium-137, which will provide gamma rays for research in radiation chemistry.

The radioactive isotope is contained in twelve capsules of stainless steel. The capsules were brought to Tech from the Oak Ridge National Laboratory in a special lead carrier that weighed 3750 pounds. The carrier contained a mechanism for remote positioning of the capsules inside, enabling the transfer of the capsules to a floor well to be a completely shielded operation.

The floor well is a special facility that was a part of the original design of the building. It is twelve feet deep and includes concrete and lead shielding. Built into the well is a cylindrical nest of twelve tubes. The capsules of cesium-137 were pushed into the tubes through the bottom of the lead carrier. They were placed about three feet from the bottom of the well, where they will remain permanently.

Specimens to be irradiated by the source will be lowered into the well. The half-life of cesium-137 is approximately 30 years, insuring a long period of useful radiation.

This is the first time cesium-137 has been used in this type of facility. It was designed by Tech researchers Richard Palmer and Randall W. Carter.

The facility will be used for a wide range of studies in radiation chemistry, including projects in Georgia Tech's $150,000 program of research on the industrial uses of radioisotopes. Already experiments are being made on the effects of gamma radiation on kaolin. More information on the uses of the irradiator will appear in future issues of the *Research Engineer*.

Georgia Tech arranged for procurement of the source through the Office of Isotope Development, Atomic Energy Commission, Washington. The contract between Tech and the Government for use of the source will be administered by the Commission's Savannah River Operations Office in Aiken, S. C. The source was encapsulated for Tech by the Oak Ridge National Laboratory.

Electroforming at Georgia Tech

by John Cerny, Assistant Research Engineer

ONE OF THE NEWER fabrication processes at the Georgia Tech Engineering Experiment Station was first developed over 100 years ago. The process of electroforming (i.e., production of articles by electro-deposition) was reportedly discovered in 1838 at the Academy of Sciences in St. Petersburg, Russia, by one Professor Jacobi[1]. Similar claims were made in England in 1839 by Spencer and Jordan, but Jacobi is generally credited with the discovery of electroforming, or galvanoplasty, as it was then known.

Recently, when various microwave components were needed on projects at the Engineering Experiment Station, it became apparent that electroforming was the logical method of fabricating these complicated parts. Commercial electroformers throughout the country were approached for this fabrication work, but various difficulties arose which led to the development of an electroforming capability at Georgia Tech. The main difficulty in subcontracting this specialized work was in maintaining liaison and control over the fabrication of components.

Considerable assistance in setting up this process at the Engineering Experiment Station was received from personnel at Bell Telephone Laboratories at Holmdel, New Jersey. They too had experienced difficulties in outside contracting and had finally developed their own techniques and facilities. Among others providing assistance were personnel in the Electroplating Projects Department of Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

Electroforming is a method of producing a part by electrodeposition of a metal to required thickness on a mandrel (usually removable), which is analogous to the casting of a metal in a mold. The metal deposited, which constitutes the electroform, may be one of almost two dozen pure metals that can be electroformed in aqueous baths, though copper, silver and nickel are most commonly used[2]. The required thickness may range up to an inch or more depending on final use, and the mandrel may be permanent, soluble, or fusible, depending on how complicated and exact the final part must be. In any case, the electroformed part has characteristics exactly reproducing the finish and dimensional accuracy of the surface of the mandrel on which the metal is deposited. Electroforming is therefore a logical method of fabricating complicated parts where internal machining is difficult, costly, or impossible, and where inside dimensions and surface finish are critical.

Typical applications of electroforming are in the production of rubber and plastic molds, reflectors, currency printing plates, bellows, nozzles, and microwave components.

Electroforming at the Engineering Experiment Station has consisted mainly in the production of complicated microwave components for research and development programs. (See accompanying illustrations). These parts are well suited to fabrication by electroforming, as internal surfaces must be of fine surface finish and

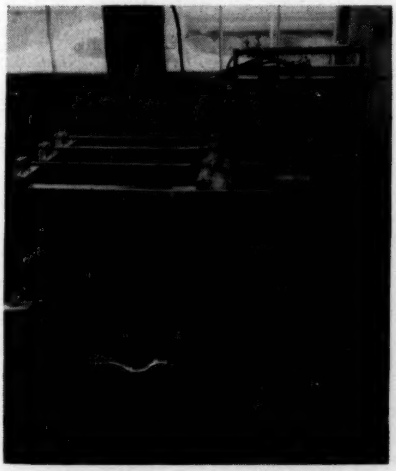
held to close tolerances. The parts often have complex internal areas inaccessible to ordinary forming methods, and the required degree of conductivity is obtained through deposits of copper or silver.

Best results have been obtained in the deposition of copper from a standard sulfuric acid-copper sulfate plating bath with brightener[3]. These deposits, in conjunction with proper bath control and electroplating techniques, are fine-grained, smooth, and ductile, with fairly uniform build-up and satisfactory machining characteristics.

The electroforming equipment at Georgia Tech consists of a selenium rectifier for supplying currents between zero and 50 amperes, a 30-gallon stainless steel tank, and a motor-driven pump-filter unit to provide continuous solution filtration and agitation. This filtration and agitation results in improved deposit appearance with less roughness, and optimum plating speed is obtained from continuous replacement of depleted metal ions around the work piece.

Increased plating speed to approximately 300 amps/ft^2 current density is possible with high agitation and adequate control of all operating factors. However, most electroforming is done at 20-50 amps/ft^2 current density. Operation and control of the standard sulfuric acid-copper sulfate plating bath with brightener is discussed by several authors[4,5].

Shown below are Georgia Tech's 50-gallon electroforming tank and selenium rectifier.

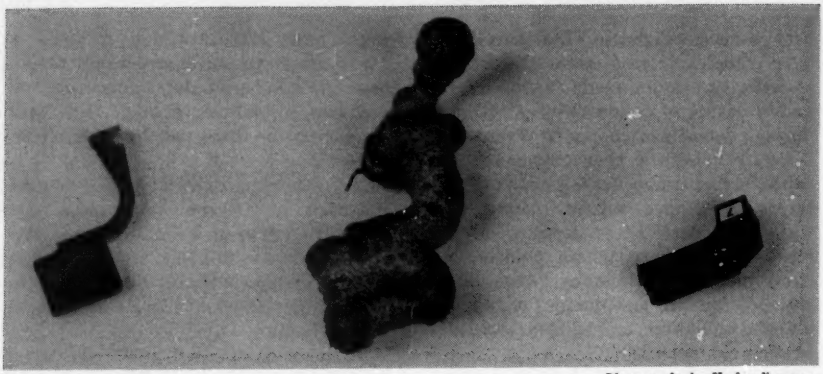


Various electrodeposits and mandrel materials have been investigated. The standard potassium cyanide copper plating bath was initially set up, but it proved to be a difficult bath to control and was passed over in favor of the acid-sulfate bath.

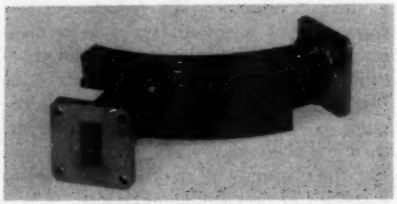
Permanent mandrel materials which have been investigated include types 316, 416, and 17-4 PH stainless steel. The excellent corrosion resistance, machineability and low coefficient of thermal expansion compared with copper, indicate 17-4 PH to be the best suited permanent mandrel material used with the acid-sulfate bath. Passivating in a dilute potassium dichromate solution results in a thin, conductive film which permits formation of a sound, accurate replica, but which is weak enough to permit separation. These permanent mandrels offer high scratch resistance, and do not require a conductive coating. However, their use is limited to electroforms allowing their complete removal as integral mandrels or mandrel components.

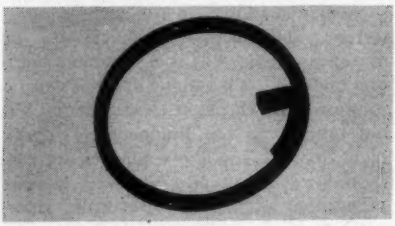
Soluble mandrels in use include polystyrene and methyl methacrylate, or plexiglas. Aluminum is a common mandrel material (it is soluble in a hot caustic solution), which has been considered but not utilized by the Engineering Experiment Station. The above plastics are easily molded and readily dissolved, thereby permitting intricate electroforms. However, they are easily scratched, must be made electrically conductive, and may warp with change of temperature (i.e., in an evaporative coating process).

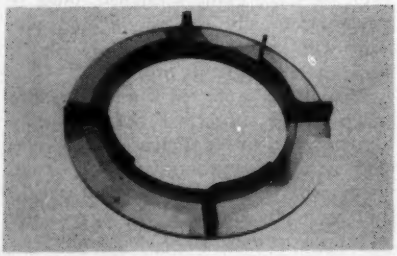
Plexiglas is preferred if much mandrel machining is concerned, but rigid polystyrene gives better dimensional stability and is easily injection molded where many parts are involved. These plastics can be made conductive by evaporation of approximately 1000 angstroms (ap-



Photographs by Harley Furgeson







Above: Three stages in the electroforming process are seen left to right: the plastic mandrel, the copper electroform, and the machined electroform with mandrel dissolved. *Left, top to bottom.* A series of close-ups shows: a vacuum metallized plastic mandrel (note shims); A finished electroform with flanges added; a finished circular product; complex plastic mandrel (about 10 in. diam.)

proximately 4 x 10^{-6} inches) of gold. Gold is usually chosen for reasons of conductivity, tarnish resistance, and ease of vacuum deposition, although other metals can be utilized.

A second method of obtaining a conductive coating is by applying a special silver paint[6]. However, vacuum metallizing capabilities, which already exist at the Engineering Experiment Station, result in coatings which are smoother, thinner, and more conductive.

The only fusible mandrel which has been investigated is Cerrocast, a bismuth-tin alloy with a melting range of 281°-338°F and a shrinkage of 0.0001 in/in. This material has characteristics similar to soluble materials in that it is soft and easily scratched. It may be cast into complicated molds, but it is difficult to completely remove the Cerrocast from the electroform.

Preparation for electroforming is the same as preparation for electroplating. Mandrel preparation, cleaning, and masking, and the application of current is exactly the same for thin deposits as for

thick. Bath filtration, agitation, and current density are more important in forming thicker deposits because of the greater structural integrity required of electroforms.

The time required to build up a certain thickness in the acid-sulfate bath may be estimated[7] from the factor of approximately 18 amp/ft^2 required to deposit 0.001 in/hr. This factor applies only on uniformly shaped cathodes, because current concentration on projections results in thicker than average deposits, while build-up in recesses is thinner than average. For this reason outside corners of mandrels should be rounded, and sharp inside angles replaced with fillets where possible.

Sharp inside corners present a problem in electroforming, because columnar crystals grow out from the sides of the angle to meet in a plane bisecting the angle, and the metal strength in such a cleavage plane is very low (see micrograph). Where sharp internal angles with some strength are required, a substantial thickness of metal can first be deposited in the corner, following which a fillet can be formed of solder, plastic metal, or low-melting alloy[8]. A sound deposit can then be built up over this fillet. Nonconducting shields and auxiliary anodes may be utilized to attain electroforming of more uniform thickness. Troubleshooting techniques to solve problems of faulty adhesion, pitting, roughness, and lack of uniformity have been reported by several authors[9], [10].

After building up to the required thickness, the electroform is removed from the plating bath, machined where required, and separated from its mandrel. Electroforms deposited from the acid-sulfate bath are satisfactorily machined at speeds and feeds recommended for copper. All machining is done before removing the mandrel to prevent collapsing electroformed shells due to clamping and tool pressures. Care must be taken to prevent tearing deposited metal away from the mandrel by improper machining techniques.

After machining of the electroform, mandrel removal may be accomplished by several methods. 17-4 PH stainless steel mandrels may be removed from copper electroforms by heating to 500°-600°F and separating, taking advantage of the differential coefficient of thermal expansion. Permanent mandrels should have slight draft where possible to facilitate removal.

Soluble plastic mandrels may be removed by heating, cooling, or dissolving in a strong solvent such as methylene chloride. Heating and cooling are applicable where the integral mandrel, or mandrel components, can be separated. Heating may be accomplished in an oven within the softening range of the plastic; cooling, which makes better use of the thermal coefficients involved, may take place in a "dry ice" refrigerator. More intricate mandrels must be dissolved away, preferably while agitating.

Electroforming copper from a sulfuric acid—copper sulfate bath on plastic mandrels has proven to be an excellent means of fabricating complicated components. Other electrodeposits and mandrel materials have been considered, some of which are satisfactory for particular applications, depending on complexity of the mandrel and the required deposit characteristics.

Metals may be deposited one over another to give improved combinations of strength and conductivity. This may include deposits of nickel over silver, nickel over copper, and copper over silver. One characteristic of nickel plating in the past has been highly stressed deposits. Recent refinements, especially in the sulfamate bath, have resulted in relatively stress-free deposits well suited to electroforming and machining[11].

One other metal deposit which has not been investigated at Georgia Tech, but should be mentioned, is aluminum. Research and development has resulted in the electroforming of thick, sound, aluminum deposits[12], [13]. Some difficulties remain in the process, but future improvements could be expected which

Micrograph (280X) of electroformed corner shows crystals meeting in a cleavage plane.

would allow many new electroforming applications, especially in the aircraft industry.

Electroforming has found many applications where internal characteristics are difficult to create by other means, and where high surface finish and close dimensional tolerance are required. The use of this production method will surely increase as engineers become more familiar with its possibilities, and as further advances are made in electroforming solutions and techniques.

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5. *Wes-X 313 Acid Copper Plating Process, op. cit.*

6. *Conductive Coating Materials, Ceramic Products Bulletin No. CP2-356* E. I. duPont de Nemours and Co., Inc., Wilmington, Del., (Conductive Coating No. 4922).

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8. Lamb, Vernon A. and William H. Metzger, Jr., *Electroforming—A Method for Producing Intricate Shapes*, The International Nickel Co., New York, 1954, p. 6-8.

9. Graham, *op cit.*, p. 227.

10. Feldman, *op. cit.*, p. 11.

11. "Stress-free Nickel Plating," *Metal Progress*, Vol. 73, No. 4, April 1958, pp. 90-92.

12. Heritage, R. J., *The Deposition of Aluminum from Non-Aqueous Electrolytes*, ASTIA Report No. AD-79802, Radar Research Establishment (Great Britain), 1955.

13. Hickey, Jean, Vernon Lamb, and Abner Brenner, *Electrodeposition of Aluminum*, ASTIA Report No. AD-36658, National Bureau of Standards, Washington, D. C., 1954.

MINERALS COMMITTEE REPORT

THE MINERALS Advisory Committee, which consists of leading men in Georgia industry, government and research organizations (*Research Engineer*, December, 1959), met at Georgia Tech on January 15, 1960.

Among the topics of discussion was the desirability of developing a source of gravel in Georgia for a southeastern "massive" silica producer that uses about 100,000 tons of gravel annually.

It was announced that a State-supported investigation into the feasibility of producing a synthetic ball clay for the whiteware and other manufacturers is now active. It appears that new burned lime plants in Georgia will be constructed.

Mineral resources surveys have been or almost completed for Hancock, Crawford and Bibb counties. These surveys are being made in connection with a broad study of Georgia Tech's Industrial Development Branch on the industrial potential of the Macon area.

Georgia Tech is assisting the State Department of Mines, Mining and Geology in a preliminary investigation for practicable limestone "centers" in Southwest Georgia. A hitherto unreported escarpment south of Albany was found and the surface boundaries of this geologic feature are being determined.

Ingols, Robert S., Robert H. Fetner and William H. Eberhardt, "Determining Ozone in Solution." Reprinted from Advances in Chemistry Series, No. 21, 1959. Reprint 141. Gratis.

Stable ozone solutions have been analyzed by various techniques recommended in the literature, and results are compared and interpreted. Data are presented to correlate the quantity of the by-product oxygen from the ozone reaction with the apparent amount of original ozone.

△

Fetner, R. H. and R. S. Ingols, "Bactericidal Activity of Ozone and Chlorine against Escherichia coli at 1° C." Reprinted from Advances in Chemistry Series, No. 21, 1959. Reprint 142. Gratis.

The bactericidal effects of ozone solutions were tested against E. coli suspensions at 1°C., and the lethal dose was determined as that quantity of ozone necessary to produce a detectable residual in solution. Under the conditions of the experiments this was 0.4 to 0.5 mg. per liter. A comparison of the bactericidal activity of chlorine under similar conditions emphasized the different mode of the two agents.

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Belser, Richard B. and Walter H. Hicklin, "Temperature Coefficients of Resistance of Metallic Films in the Temperature Range 25° to 600° C." Reprinted from Journal of Applied Physics, March, 1959. Reprint 140. Gratis.

The temperature coefficients of resistance (TCR) of films of sputtered Au, Ir, Mo, Ni, Pd, Pt, Rh, Ta, and W, of evaporated Al, Cr, Ti, and Zr, and of the alloy films Pt-Au, Pt-Ir, and Pt-Ni have been measured *in vacuo* over the temperature range 25° to 600°C; the film thickness range was 75 to 2000 A. The TCR values of films of the substantially pure metals were in the range 1/3 to 2/3 those of the respective bulk metals whether deposited on glass, Vycor, or Stupalith substrates. The departure of the conditions of growth of the film from those usual for the bulk metal, i.e., rapid cooling effects and impurities present, contributed imperfections which reduced the TCR of the film. The TCR values of alloy films were low, 0.0004 per °C for Au-Pt, and resistivities were 3 to 4 times that of either constituent. The TCR values of sputtered films of Mo, W, and Ta and of evaporated Cr, Zr, and Ti were generally less than 0.0001 per °C. Electron diffraction examination of films of these latter metals revealed oxide inclusions in the films. The presence of the oxide of the metal reduced the TCR and increased the R/sq of the film as compared to those of the pure metal. Only films of gold, platinum, and iridium were corrosion resistant in air near 600°C. Overcoats of evaporated SiO provided partial protection from the others. Powers up to 15 watts were dissipated by refractory metal films only 1/32 by 1/2 in. and about 750 A thick. These high values contrasted with less than 1/4 w for a gold film of similar dimensions.

▲

McDaniel, E. W. and M. R. C. McDowell, Low-Field Mobilities of the Negative Ions in Oxygen, Sulfur Hexafluoride, Sulfur Dioxide, and Hydrogen Chloride." Reprinted from The Physical Review, May 15, 1959. Reprint 143. Gratis.

Measurements of the low-field mobility of the negative ions in O_2, SF_6, SO_2, and HCl are described. The results are 2.46, 0.57, 0.35, and 0.71 cm^2/v-sec, respectively, reduced to 0°C and 760 mm Hg pressure. A quantum-mechanical theory of ionic mobility is outlined and applied to the gases investigated experimentally. Comparison of the experimental and theoretical results indicates that the oxygen ion is O_3^-, but attempts to identify the ions in the other gases are inconclusive.

These publications and the complete list of technical publications may be obtained by writing Publications Services, Engineering Experiment Station, Georgia Institute of Technology, Atlanta 13, Georgia.

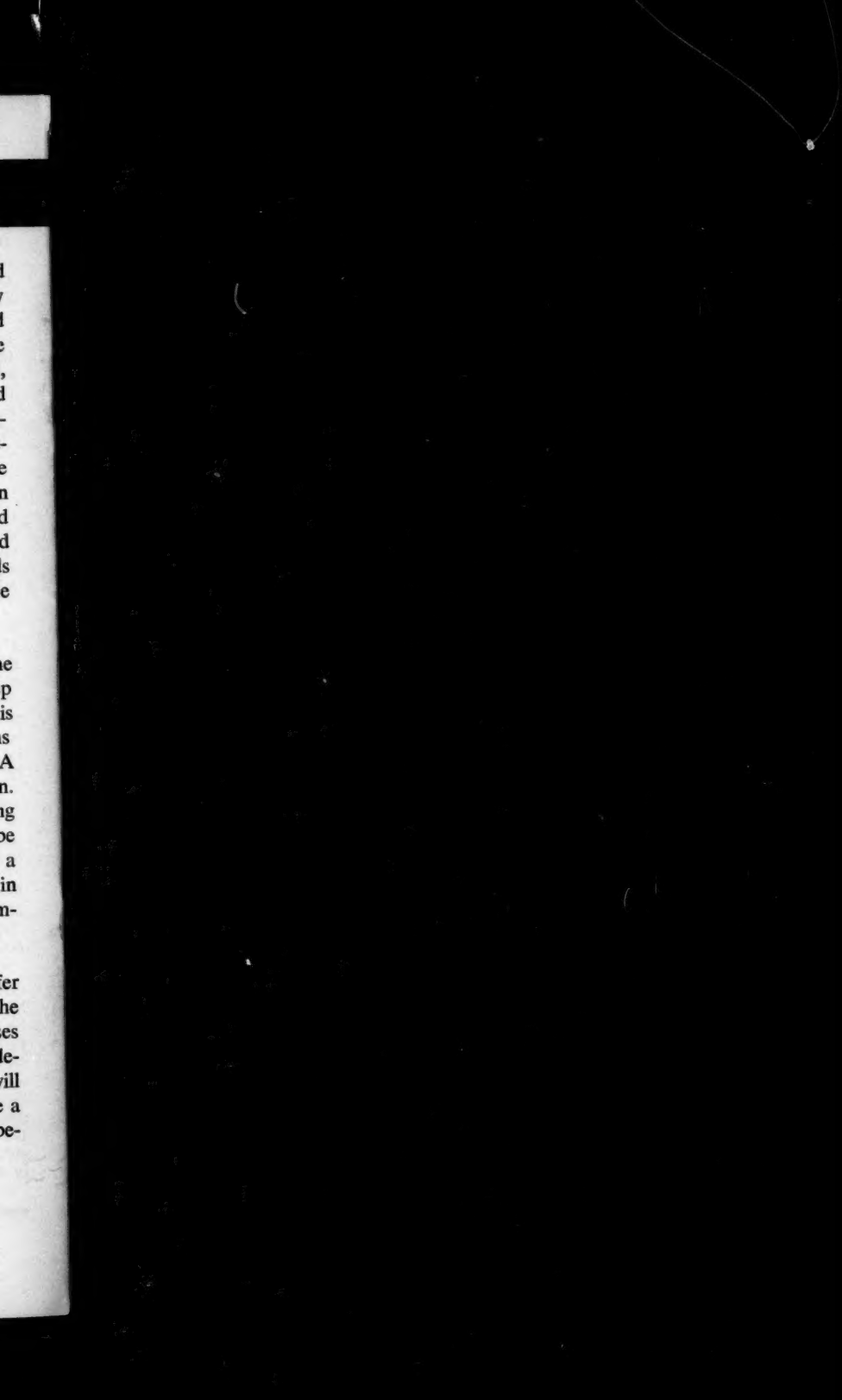
Edited in Retrospect

shop talk, 500 B.C.

• Our February issue on ceramics research prompted a thinking friend of ours to point out that ceramics play an important role in anthropology. In fact, he suggested that ceramics may even lead to great revelations in the study of dead languages. In making pottery, he explained, the ancient craftsmen would spin the clay on a wheel and form the shapes with their fingers. It is possible that a potter's fingernail could act as a phonograph needle, transmitting voice vibrations as he talked or sang while he worked. The resulting fine grooves in the clay would then be baked in, providing a permanent recording. We need only to find pots with adequate fingernail grooving and play them back at the right speed. Then after thousands of years of silence, the voices of the ancients would be heard again.

computer review

• This issue's trio of articles on the operations of the Rich Electronic Computer Center is an attempt to keep our readers informed of the rapid developments in this facility. Since early 1959, the installation of the Burroughs 220 and the core addition to the memory of the ERA 1101 have doubled the Center's capacity for computation. And the importance of the highly skilled staff in providing the services available at the Computer Center cannot be overemphasized. These articles are intended to present a small sample of the work that is currently underway in both the hardware and mathematical aspects of the Computer Center's activities.

atoms on the agenda

• For the coming June issue we are planning to offer two or three examples of Georgia Tech's progress in the nuclear sciences. One of these will be a report on the uses of the new cesium-137 radiation source, which is described on pages 12-13 of this issue. Another article will report on the research reactor project. We hope to have a third article on the theoretical and experimental work being done in the area of atomic collisions.